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BIOLOGICAL IMPLICATIONS OF THE MARS '94 MISSION

Final report: Grant NAGW-2378

submitted to:

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HISTORICAL INTRODUCTION

The work on this grant began approximately five years ago. At its inception, the Soviet plans for the next phase of Mars exploration were predicated on the assumption that there would be two related missions, one in 1994 and the other in 1996. The 1994 mission was to consist of two spacecraft, each carrying an orbiter, several small surface "stations" and, possibly, penetrators. In addition to the imaging of the local terrain, investigations of exobiological interest on this mission were to include analyses of the elemental composition of surface samples, including several of the so-called biogenic elements. Details of the 1996 mission were very sketchy, but early descriptions of the mission included many aspects of clear concern to exobiologists. For the 1996 mission, plans called for the inclusion of penetrators, balloons, and a descent module containing a small rover which was to provide imaging of the surrounding regions, elemental analyses, and an instrument, poorly defined at the time, to measure bound volatiles through the evolution of bound gases and possibly organic compounds in the Martian regolith. This instrument was expected to consist of some kind of pyrolytic capability coupled to thermal analysis and a gas chromatograph (GC), and was projected to be developed with participation by Russian and German specialists. Other apparatus, initially described for possible flight on these two missions, included almost two dozen global and *in-situ* instruments.

This proposal was conceived as an opportunity to interact with the scientists who would be selected for these missions in order to bring exobiological issues to their attention, since many of the proposed instruments were highly relevant to exobiological objectives. At the outset, this was to involve, among other things, trying to influence the design of the instruments so as to optimize them for providing data for exobiological issues; to influence the choice of targets for high resolution imaging; to influence the detailed plans for geochemical analyses.

Accordingly, my early efforts were expended in making contact with several of the "Mars '94" and "Mars '96" science teams. Specifically, in March 1991, I met with Prof. J. Bibring (Principal Investigator for the OMEGA instrument) at a JPL meeting of parties interested in the Mars '94 OMEGA *instrument*. There, I presented a briefing on the utility of this global spectroscopic instrumentation for exobiological purposes.

During the February to November 1991 time frame, I was also deeply involved with the GC-DTA instrumentation that had been proposed for the '96 Rover. Recognizing the importance of this instrument for exobiology and based upon discussions with Lev Mukhin (Science chief for the proposed USSR rover at the time), I saw a potential weakness in the delineation of scientific objectives for this instrument. A German scientist (Dr. Helmut Rosenbauer, Max Planck Institute at Lindau) had been selected to be co-investigator with Mukhin. But Rosenbauer's expertise was in space physics and instrumentation, while Dr. Mukhin had only limited experience with either gas chromatography or DTA. Accordingly, after an invitation by Dr. Barsukov for US participation in the development of instrumentation for the GC part of this instrument, I made attempts to bring the key Soviet and German parties together with GC experts at the NASA Ames Research Center (Glenn Carle and Rocco Mancinelli) in order to generate the best possible concept for this instrumentation, taking advantage of the individual expertise that these three groups had to offer. These attempts finally resulted in at a meeting held November 14, when a tentative plan, which could involve US participation, was agreed upon for the development of the GC-DTA instrumentation. In later meetings with the principals, it became clear that, at best, only a small role for the US was envisaged by Rosenbauer; that the substantial funding that would be required even for this role was dubious; and that completion of a final operational instrument was also problematical due to insufficient funding of both Rosenbauer and Mukhin. As a result, I abandoned further direct involvement in this aspect of the mission.

By late 1991, I had made progress in initiating a collaborative effort with Dr. Ron Greeley (Arizona State University) with the long-term objective of developing a list of sites on Mars that would be of potential interest to exobiologists. I was successful in bringing together a small team consisting of myself, Drs. Des Marais and Farmer (NASA-Ames), and Dr. Greeley, to develop plans for this aspect of the USSR missions. Initially, together with the other members of this team, I participated in the Mars Analog Site Study (MASS) that was conducted by ASU in the spring of 1991.

Subsequently, as a follow-on to this study, Dr. Greeley agreed to collaborate with the Ames scientists and myself to pursue a larger study, one whose objective was to integrate the exobiological goals inherent in Mars '94 and Mars '96 missions with the best available information about the topography and characteristics of the Martian surface and to identify sites of particular interest to exobiology within the envelope of potential landing sites. For this study, Dr. Greeley assigned Ms. Landheim to be the key participant from ASU. Her role was to research the available Viking photographs and maps of Mars for sites that might satisfy the desires of the exobiological community. Ms. Landheim was to be funded through a subcontract from Santa Clara U. to ASU under this grant.

This collaboration led to a number of subsequent highly beneficial actions: 1) After the MASS study, Ms. Landheim began the study of Viking images and, using the criteria developed for the MASS study, characterized a number of exobiologically-relevant sites on Mars, 2) a paper describing the Mars site analyses was presented at the World Space Congress, 3) this work was also reported, and well-received, at the Mars Geological Mapping meeting and also at the meeting of the US/Russian joint working group on Solar System Exploration.

At a meeting on site selection, held in Houston in March 1992 at the Lunar and Planetary Institute, I prepared material for presentation at this meeting showing key exobiological objectives and general characteristics of preferred landing sites, i.e., sites where water-ice might be expected at the present time, or sites of possible former standing bodies of water, such as convergent drainage areas in the cratered terrain and the termini of flood regions. Also at this meeting, I had discussions with Prof. Neukum (Principal Investigator on the Mars'94 Orbiter imaging system) about the interests of the exobiology community in his global imaging system , and later transmitted to him a provisional list of sites of exobiological interest.

During this same period, i.e. early 1992, Dr. Chris McKay (NASA-Ames) asked me to join a group of individuals interested in the possibility of providing a simple instrument to identify or characterize the reputed Mars surface "oxidant" that had been indicated in the Viking lander experiments. Working with McKay and others from JPL, Cal Tech, Martin-Marietta, Sandia Corp., and NASA, an Instrument Definition Team was empaneled. My contributions to the deliberations of this group have centered around developing a science rationale for doing the measurements; for constraining a number of suggested approaches to a few relatively simple measurements; for emphasis on science controls for the instrumentation; and for specifying the organic compounds that should be included in the measurement assays. Later in the same year, NASA selected the Mars Oxidant experiment (MOX) to be a US experiment on board the then Mars '94 small landers and work on this instrument has proceeded expeditiously ever since.

By 1992, it also became evident that the original concept for the two sets of Soviet missions to Mars was in trouble. Planning for the '96 penetrator-balloon-rover mission was rapidly receding. As problems mounted for these missions, it was first decided to delay both of the missions until the subsequent opportunities. Thus, Mars '94 was to become Mars '96, and Mars '96 was to become Mars '98. Then, shortly thereafter, the Mars '98 mission was canceled and it appears now that there are no firm plans for any Russian follow-on missions beyond the Mars '96 mission.

As of this writing, despite the two-year slip in its launch date, the Mars '96 mission still appears to be on track and my own activities in connection with this mission have narrowed to participation mainly along two lines: a) the identification of sites that warrant further detailed examination by the Mars '96 high resolution cameras, and b) the development of the Mars Oxidant experiment (MOX).

SUMMARY OF MAJOR DEVELOPMENTS RESULTING FROM THIS GRANT

Summaries of my activities in connection with this grant have been given in previous reports (20 Nov., 1991, 18 Dec. 1991, 20 Apr. 1992, 31 Dec. 1992, 31 Dec. 1993, and 30 May 1995). What follows below is an extension and up-dating of these earlier reports.

A. Characterization of Exobiologically Relevant Sites on Mars.

The analysis of available Viking imaging data in collaboration with Drs. Des Marais and Farmer (NASA-Ames), and Dr. Ron Greeley and Ms. Ragnhild Landheim (Arizona State

University), through a sub-contract to this grant, has proven to be extremely valuable. These studies revealed upwards of two dozen sites on Mars that clearly have relevance to exobiological objectives. These sites were included in the latest version of the "Mars Landing Site Catalogue". Specific attention was later paid to the local and regional geologic mapping of the *Gusev crater-Ma'adim Vallis* region. The geological mapping allowed defining the *Ma'adim Vallis* source area and delineating the *Ma'adim Vallis* watershed, and the geologic processes and events contributing to the releases of water in *Ma'adim Vallis* were assessed.

The geologic mapping involved estimating the percent contribution of each geologic unit in the watershed to sedimentation in *Gusev* crater. This mapping resulted in the assessment that the crater floor is a high priority target for exobiology. Analysis of ancient impact basins in the map area and nearby north-south trending fracture systems were interpreted to have influenced the development of *Ma'adim Vallis*. The source area appears to be located in the areas of chaotic terrain south of *Ma'adim Vallis*. East-west trending fractures extending from Tharsis are interpreted to have intersected aquifers in this area and caused episodic releases of water that contributed to the filling of *Gusev* crater.

In addition to these detailed studies of the *Gusev* crater area, contributions were made in connection with the selection of a nominal landing site for the Mars Pathfinder lander. Although, the *Gusev* area falls outside the boundaries available for Pathfinder, experience in mapping the area enabled a rapid assessment to be made of several additional sites on Mars, including the *Ares* site, which was ultimately selected as the tentative Pathfinder site.

On the basis of our studies, Dr. Greeley, who is also a member of the Russian Mars '96 Orbiter Imaging Team, recently submitted these three recommendations as our highest priority sites for high resolution imaging:

- for paleolake basins: *Gusev Crater* and *Parana Vallis*;
- for thermal springs: *Dao Vallis* outflow channel on the southern flank of *Hadriaca Patera*.

In addition, it was suggested that detailed coverage be made of the circular chaos regions at the head reaches of *Tui* and *Ares Valles* , to support the Pathfinder mission site recommendations.

It should be noted that, as of this writing, there is still uncertainty about the orbit for the '96 mission, so it is not clear whether the mission will be able to implement our recommendations.

B. The Mars Oxidant Experiment

Almost from the inception of this grant, I have functioned as a member of the MOx Instrument Science Definition team, helping to develop science and operational criteria for this instrument, now scheduled to be part of the Mars '96 payload. I've been involved in team meetings and decision-making activities of the team. I am a co-author of two papers describing the instrument currently being produced. My main objectives in connection with the MOX have been

to include, as test materials, organic compounds related to those that have been shown to be present in carbonaceous chondrites. As of this writing, the list of coatings for the instrument has been finalized as follows:

- Reference Coatings:
  1. Bare SixNx
  2. Ti, Pt, Thick Au or Ti, Thick Au or Cr, Thick Au
- Reactive Metals:
  1. Ti, thin Au
  2. Pd
  3. Ag
  4. V
  5. Ti
  6. A
  7. Mg
- Semiconductors:
  8. PbS
- Kerogen-like organics:
  9. Ni, Kerogen (H:C=1.2)
  10. Ni, Kerogen (H:C=0.5)
- Non-kerogen organics:
  11. Ti, Au, L-cysteine
  12. Ti, Au, D-cysteine
  13. Ni, C60
  14. Ni, Bromcresol Purple
  15. Ni, Bromphenol Blue
  16. Ni, Thymol Blue
  17. Ni, Fluorescein
  18. Ni, Fe Tetraphenyl Porphyrin
  19. Ni, Copper phthalocyanine
  20. Ni, Chlorophyllin

As of this writing, critical decisions have yet to be made before the MOX is ready for its investigations on Mars. In addition, the Science team has just begun the task of defining protocols for general characterization of the instrument.

Current *plans* call for the fabrication of "Witness" cells, some of which would be kept under conditions approximating those that the MOX will see during its trajectory to Mars, and then subjected to tests based on the data that will be returned. Other "Witness" cells would be subjected to engineering and science testing as soon as they become available. These plans also call for the development of models (e.g., atmospheric, thermal) that might be used in interpretation of the data frolm Mars. Finally, the plans also require that *all* of the coatings be characterized with respect to their reactivity. It is envisaged that extensive science testing will be carried out by the Science Team that is ultimately to be selected for this instrument. It is *unfortunate, in my view, that-due* to the pressures of fabricating this complex instrument - it was not possible to conduct more science testing. So far, laboratory testing of many - but not all - of

the individual coatings has been accomplished under "idealized" conditions designed to test their feasibility for use in the MOX.

The present status of the MOX instrumentation can be summed up as follows:

- Both MOX sub-systems have been tested and calibrated. Two "Flight-like" instruments have been fabricated. One has been "sterilized" and delivered to Moscow awaiting integration into the small lander. The other is in Helsinki undergoing electrical engineering tests before being returned to JPL for "sterilization" and later shipment to Moscow in the March-April timeframe.

- Problems remain with respect to the sealing of the cells, and these must be resolved in the very near future, as the JPL schedule is predicated on shipment of the completed Flight instruments by May 31, 1996. Presumably they are to be installed on the small landers at the Baikonur launch facility.

C. Related activities

Throughout the course of this grant, I have actively participated in the development of strategic plans for exobiological investigations on Mars; have participated in activities of the Mars Exploration Long Term Strategy Working Group (MELTSWG); and have also in discussions with key US (D.L.DeVincenzi) and USSR/Russian (M. Ivanov) individuals involved in planetary protection implementation for the Mars '94 ('96) and '96 ('98) missions.

PUBLICATIONS RESULTING FROM NASA GRANT NAGW-2378

"Survey of Oxidants in the Mars Near-surface Layer," Stoker, C., A. Seiff, H.P. Klein, C. McKay, and R. Day, in: *Exobiology on Mars,* NASA Conf. Publ. 10055 (1990).

"Sites for Exobiology Studies on Mars," H.P. Klein, R. Landheim, and R. Greeley, p. 581, Abstracts, World Space Congress, Washington, D.C. (1992).

"Mars Exobiology Landing Sites for Future Exploration," R. Landheim, R. Greeley, D. Des Marais, J.D. Farmer and H. Klein, abstract, Lunar Planet. Sci. Conf. XXIII (1992).

"Sites for Exobiology Studies on Mars," Harold P. Klein, Ragnhold Landheim and Ron Greeley, COSPAR abstract 1992.

"The Solar System: Importance of Research to the Biological Sciences," Harold P. Klein, in: *Exobiology and Solar System Exploration,* NASA SP 512, pp. 19-27, 1992.

"Landing Sites on Mars for Exobiology," Ragnhild Landheim, Ronald Greeley, Jack D. Farmer, David J. Des Marais, and Harold P. Klein, in: *Case for Mars V* (1993).

"Mars Exobiology Landing Sites for Future Exploration," Landheim, R., R. Greeley, D. DesMarais, J.D. Farmer, and H. Klein, abstract, Lunar Planet. Sci. Conf. XXIV, 845-846 (1993).

"Exobiology Sites on Mars for Future Exploration," Landheim, R., R. Greeley, J.D. Farmer, D. DesMarais, and H.P. Klein, abstract, Planetology and Origins of Life Conf., 1993.

"A Strategy for Mars Exobiology," Jack D. Farmer, David J. Des Marais, and Harold Klein, Report to Mars '94/'96 Imaging teams, Apr. 1994.

"Potential landing sites for Mars Pathfinder," Kuzmin, R., R. Landheim, and R. Greeley, Mars Pathfinder Landing Site Workshop, Lunar Planet. Inst. Tech Rpt. 94-04, pp. 30-31 (1994)

"Site Selection for Mars Exobiology," J. Farmer, D. Des Marais, R. Greeley, R. Landheim and H. Klein, Proc. World Space Conference, 29th Plenary Mtg. (COSPAR), and *Adv. in Space Research*, 15(3): 157-162 (1995).

"Stratigraphic assessment of Gusev Crater as an exobiology landing site," Landheim, R., N.A. Cabrol, R. Greeley, and J.D. Farmer, Lunar Planet. Sci. Conf. XXV, 767-770 (abstract), 1994.

"Exobiology," J.D. Farmer, D.J. DesMarais and H.P. Klein, in *Mars Landing Site Catalog,* R. Greeley and P.E. Thomas, eds., NASA Ref. Publ. 1238 (1995).

"Mars Surface Chemistry Investigated with the MOx Probe: A 1-kg Optical Microsensor-based Chemical Analysis Laboratory," Grunthaner, F.J., A.J. Ricco, M.A. Butler, A.L. Lane, C.P. McKay, A.P. Zent, R.C. Quinn, B.R. Murray, H.P. Klein, G.V. Levin, R.W. Terhune, M.L. Homer, A. Ksendzov, and P. Niedermann, NASA Tech. Report, (1995 in press).

"Investigating the Surface Chemistry of Mars," Grunthaner, F.J., A.J. Ricco, M.A. Butler, A.L. Lane, C.P. McKay, A.P. Zent, R.C. Quinn, B.R. Murray, H.P. Klein, G.V. Levin, R.W. Terhune, M.L. Homer, A. Ksendzov, and P. Niedermann, Analytical Chemistry, pp. 605A-610A, Oct. 1, 1995.

ACTIVITIES CARRIED OUT UNDER NASA GRANT NAGW 2387

Sept. 3-5, 1991	Participant in workshop, *"Site selection for Mars,"* also served as chairman of session: "Identification of site selection criteria," US-USSR Joint Working Group for Space Biology and Medicine, Palo Alto, CA.
Sept. 12, 1991	Met with representatives from Germany and the USSR to discuss possible collaborative effort to develop a GC-DTA instrument for Mars '96 mission, NASA Ames Research Center.
Jan. 8, 1992	Participated in *Mars Analog Site* s study, Ariz. State Univ., Tempe, AZ.
Jan. 22, 1992	Participated in workshop, *"Measurement of the redox state of the Martian regolith,"* presented an invited paper, *"Review of relevant Viking results,"* NASA Ames Research Center.
Feb. 7, 1992	Reviewed results of *Mars Analog Sites Study*, Ariz. State Univ., Tempe, AZ.
Mar. 2, 1992	Met with US participating scientists for the '94'/96 missions to discuss the potential utility to exobiology of remote spectroscopic instruments, JPL, Pasadena, CA.
Mar. 14, 1992	Met with US and Russian scientists to discuss selection of landing sites for the Mars '94 mission, Houston, TX. Discussed interest of exobiology community in landing sites, with Prof., Neukum, GDR, head of imaging team for Mars '94.
May 27, 1992	Participated in meeting to discuss Exobiology Landing Sites on Mars,.Ariz. State Univ., Tempe, AZ.
Oct. 22, 1992	Participated in meeting of Mars '94 Oxidant experiment (MOX) team, Sandia Corp., Albuquerque, NM.

Nov. 19, 1992	Participated in meeting of Mars '94 Oxidant experiment team, JPL, Pasadena, CA.
Jan. 14, 1993	Participated in Center for Mars Exploration((CMEX) meeting on landing sites for Mars, NASA Ames Research Center.
Jan. 21, 1993	Met with geologists at Arizona State University to select tentative exobiology sites for high resolution imaging during Mars '94 mission, ASU, Tempe, AZ.
Feb. 12, 1993	Participated in meeting of '94 Mars Oxidant experiment team. JPL, Pasadena, CA.
Mar. 9, 1993	Meeting with Phil Christensen and staff to discuss collaboration on Mars mineralogy, Ariz. State Univ. Tempe, AZ.
Apr 12-14,1993	Met with representatives from NASA and Arizona State University to discuss sites for exploration of Mars, NASA Ames Research Center.
Mar. 16, 1993	Participated in meeting of '94 Mars Oxidant experiment team, JPL, Pasadena, CA.
Apr. 8, 1993	Participated in meeting of Mars '94 Oxidant Experiment team, JPL, Pasadena, CA
Jan 26, 1994	Participated in Mars Rover instrumentation meeting, NASA Ames Research Center.
Apr 25-29,1994	Participated in Exobiology Strategy workshop; presented invited paper on Viking biology experiments, NASA Ames Research Center.
May 11, 1994,	Participated in Mars Surveyor instrumentation meeting, JPL, Pasadena, CA.
May 25-26, 1994	Participated in workshop on Planetary Protection for Mars landers; presented invited paper on the MOx experiment, NASA Ames Research Center.
Apr. 20-21, 1995	Participated in meeting of MELTSWG, NASA Ames Research Center.
Sept. 19-20, 1995	Participated in meeting of MELTSWG, JSC, Houston, TX.
Dec. 6-8, 1995	Participated in meeting on "Advanced Instrumentation for Mars missions," NASA Ames Research Center.

Feb. 5-6, 1996	Participated in meeting of MOX Experiment Definition team, JPL, Pasadena, CA.